



CONCEPT TEST FOR BIOLOGICAL SAMPLE TRANSPORT WITH DRONES IN LA GARROTXA

© TIC Salut Social Foundation

This project stems from the collaboration between TIC Salut Social Foundation's Personalised Digital Care Area, the Information Telecommunications and Technologies Centre, Olot and County Hospital of La Garrotxa Foundation, T-Systems, and the BCN Drone Center.

Authors: Nuria Abdón Gimenez, Pau Gallinat Muñoz, Berta Llebot Casajuana

Electronic edition: November 2024

This piece of work is subject to an Attribution - Non-Commercial - NoDerivative Works 4.0 licence by Creative Commons. The copy, distribution, and public display are permitted as long as the author and publisher are recognised and is not used commercially. The transformation of this work into a new, derived one is not permitted.



Acknowledgements

We wish to express our sincerest gratitude towards the entities that have made this project possible.

Their invaluable collaboration and commitment have been fundamental when developing this project.

We would like to firstly mention the Information Telecommunications and Technologies Centre, for their trust and support when developing this project and actively participating in its design, realisation, and evaluation.

Next up is Olot and County Hospital of La Garrotxa Foundation, especially its professionals, for identifying needs and supporting the realisation of the project and analyse results.

Finally, T-Systems and BCN Drone Center for technological support, which has helped carry out flight operations and use a drone with the required technological capacity to execute the project.

Contact

Email address:

adp@ticsalutsocial.cat

Telephone:

+34 935 532 642

Personalised Digital Care

Area Manager:

Núria Abdón Gimenez

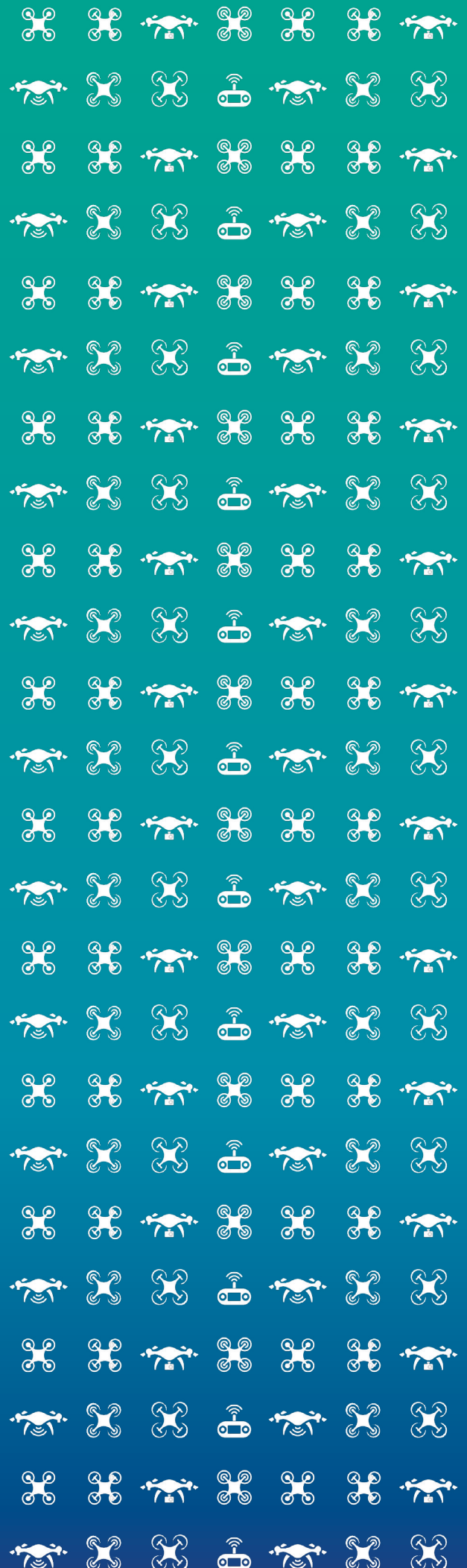


TABLE OF CONTENTS



1.	Introduction	6
2.	Theoretical context	11
3.	State of the art	13
4.	Methodology	16
5.	Piloting	30
6.	Results evaluation	32
7.	Discussion	45
8.	Conclusions	48
9.	References	50



Table of contents for figures

Figure 1. Project workflow	10
Figure 2. Garrotxa County. (1. Olot Hospital - 2. Primary Healthcare Centre Vall d'en Bas)	18
Figure 3. Google Maps of selected centres from La Garrotxa and Vall d'en Bas County	19
Figure 4. Municipal map of Sant Esteve d'en Bas and Primary Healthcare Centre Vall d'en Bas (red circle).(7)	19
Figure 5. Drone eVTOL used for the project alongside its base.	20
Figure 6. Selected centres for piloting (Google Maps screenshot)	22
Figure 7. Flight area from Primary Healthcare Centre Vall d'en Bas (green) until Olot Hospital (blue)	23
Figure 8. Flight area in La Garrotxa Volcanic Zone Natural Park	23
Figure 9. Drone landing area at Olot Hospital	24
Figure 10. Care flow at Primary Healthcare Centre Vall d'en Bas	24
Figure 11. Care flow at Olot Hospital	25
Figure 12. Indicator dimensions	26
Figure 13. Road routes between the Primary Care Centre Sant Esteve d'en Bas and Olot Hospital	29
Figure 14. Name and type of biological samples transported by drones	33
Figure 15. SUS score	35
Figure 16. SUS Scale results – usability	36
Figure 17. SUS Scale results – professional competencies	36
Figure 18. SUS Scale results – care process questions	37
Figure 19. SUS Scale results – care process questions	37
Figure 20. Bland–Altman plot of haemolysis index: drone results compared to van	39
Figure 21. Bland–Altman plot of potassium concentration: drone results compared to van	40
Figure 22. Bland–Altman plot of LDH concentration: drone results compared to van	40
Figure 23. Bland–Altman plot of glucose concentration: drone results compared to van	41
Figure 24. Correlation of differences in potassium concentration with respect to the haemolysis index	42
Figure 25. Correlation of differences in LDH concentration with respect to the haemolysis index	42
Figure 26. Correlation of differences in glucose concentration with respect to the haemolysis index	42
Figure 27. Cost distribution of the project's drone transport service	43

Table Index

Table 1. Meteorological conditions in Vall d'en Bas during the operational time slots	31
Table 2. Meteorological conditions at the Olot Station during the operational time slots	31
Table 3. Transport times by drone and van	34
Table 4. Transport duration by drone and van	34
Table 5. Mean and standard deviation of each laboratory variable for all samples transported by drone and van, difference, and percentage difference	38

1. Introduction



1.1. Motivation



1.2. Objectives



1.3. Scope



1.4. Project phases

Drones have become an innovative tool in the health field by helping with quick and efficient medicine, vaccines, samples, and equipment distribution between different healthcare actors. Furthermore, these devices allow resources to be deployed and for aerial supervision during emergencies thanks to easy access to rural areas or congested urban ones. Its use is revolutionising the way in which medical care is accessed and provided for all over the world.

A **drone** is an unmanned air vehicle that can be flown remotely or autonomously and obeys orders from a computer programme. Initially used by the military, drones are currently applied in different fields, such as **photography, agriculture, transport, and healthcare**. Drones are equipped with cameras, sensors, or other technologies to gather data or carry out specific tasks. They have become popular in both the commercial and recreational spheres thanks to their versatility.

TIC Salut Social Foundation was asked by the Catalanian Healthcare Department Innovation Commission in February 2023 to design and model integrating drones into the Catalanian healthcare system. Several actions have been carried out since then. A **work group** (with the involvement of health boards, entities, the Medical Emergency System [SEM], ICT and drone technology experts) was created; an **explanatory infographic** (1) **on how to use drones in the healthcare field was developed; and a report on incorporating drones into Healthcare** (2), which introduces the main points to integrate this technology into healthcare was written.

One of the allocated tasks is **identifying drone technology projects applicable to healthcare**. TIC Salut Social Foundation allows to research projects within the Catalanian territory by identifying needs for the subsequent design and execution of projects. **The concept test for transporting biological samples with drones in La Garrotxa** is framed in this assignment. The project consists of a concept test (CT) that transports biological samples from the Primary Healthcare Centre Vall d'en Bas to the laboratory at Olot and County Hospital of La Garrotxa Foundation.

This document exhibits the results obtained from carrying out the project driven by the Innovation Area at the Information Telecommunications and Technologies Centre (CTTI-Innovation) and TIC Salut Social Foundation, in which Olot and County Hospital of La Garrotxa Foundation and BCN Drone Centre have participated.

1.1. Motivation

The transport of biological samples in the Catalan healthcare system from Basic Healthcare Areas (Àrees Bàsiques de Salut, ABS acronym in Catalan) to testing laboratories at hospitals or reference centres is part of logistics. Transport is done by a van and generally only one collection and issuance during mornings.

Basic rural healthcare areas have other logistical problems since **poor connectivity and limited access can sometimes exist**, transport is on winding roads, which significantly increases transport times and maybe even haemolysis of samples.

Haemolysis or red blood cell breakdown causes content release

(potassium, LDH, etc.) into the blood plasma, therefore increasing the levels of these variables, **which could be altered during laboratory analysis.**

The same can happen with high transport times (because of the time between sample extraction and analysis): **glucose and LDH levels, amongst others, can become altered.** Even though in most cases the haemolysis index obtained on the road or during transport are not sufficiently elevated for relevant laboratory alterations, the ideal is to reduce them to a minimum.

Integrating drones into the care process is suggested as a tool to

improve efficiency on the transport of samples by **reducing times** - since the device can take a straight path-, which in turn increases **quality and stability** and, if needed, the frequency of current transport **These overall improvements allow not only easier logistics but also improve sample quality by minimising the amount of time between collection and analysis.**



1.2. Objectives

This project plans on **evaluating drone utility as a method for transporting biological samples** between primary healthcare centres and hospitals in order to establish the basis for a wider and more effective implementation of this technology within the Catalan healthcare system with the aim to improve future service efficiency and quality.

For this reason, this project has focused on a **concept test by transporting biological samples** using drones and evaluating results when compared to the simultaneous transport using vans.

This test must allow the advancement of an operational and managerial model scalable to the Catalan

healthcare system.

In order to evaluate drone utility, both regarding care aspects as well as route operations, **the following secondary goals were defined:**



Compare transport times and evaluate care flow of involved centres when transporting by drones and vans.



Evaluate the impact drone transport has on the quality of the samples by controlling transport conditions (temperature, shaking) and comparing to values obtained in laboratories (level of haemolysis, potassium and glucose concentrations, lactate dehydrogenase levels) in regards to van transportation.



Evaluate drone transport cost and environmental impact when compared to van transportation, which includes the cost of staff involved in the operation, equipment, and carbon footprint.

1.3. Scope

The biological sample transportation concept test design and unfolding was carried out in **La Garrotxa area**, Girona's healthcare region. The project was defined by the exhaustive analysis of **health, technical, and operational needs** as to design an adequate drone integration process. This includes identifying required resources, professionals who will participate, and determine the type of drone needed upon each case and care environment. The concept test was carried out by Olot and County Hospital of La Garrotxa Foundation (Olot Hospital

from now onwards) and the Primary Healthcare Centre Vall d'en Bas, located at Sant Esteve d'en Bas inside the hospital's area of influence. Other centres under the hospital's area of influence, as well as centres assigned to other providers, were excluded from the test.

The project centred around blood sample transportation. The logistical transport of other biological samples or resources, like medical equipment, as well as the imminent transport (not scheduled) of samples and resources,

is out of scope for this project.

A **two-week period** was defined, during which blood samples taken from patients at the CAP Vall d'en Bas were transported by drone to the laboratory at Olot Hospital.

In order to carry out the comparison between drone and van transport, the service was duplicated rather than replaced.



1.4. Project phases

The project was executed following the below stages:

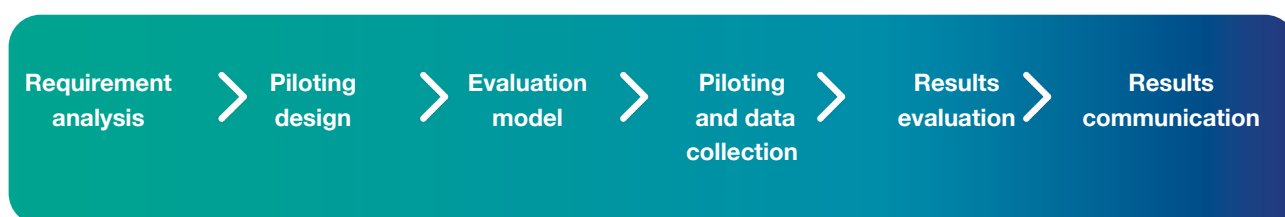


Figure 1. Project workflow

In first place, **project requirements**, including analysis of piloting environment, which drone to use, and adequate packaging for sample transport were identified.

Afterwards, **piloting was designed**, which defined the flight operation, care flow of primary healthcare centre and hospital samples, and indicators that were collected during piloting.

Then the indicator evaluation model was defined. After, the piloting phase and data collection were executed; finally, **analysis and interpreting of results from defined indicators**.

The last phase is **communicating project results**. Meetings and work sessions were held during the entire length of the project with all contributing members, which have

allowed executing each stage in a collaborative manner as previously arranged by all parties.

2. Theoretical context

Using drones in healthcare is a **technological innovation** with great potential to improve access to medical services. A drone is an unmanned/uncrewed aerial vehicle (UAV) that can be flown remotely or autonomously by obeying orders from computer software. The term drone only refers to the aircraft (2).

Several steps must be followed to guarantee service **safety, efficiency, and reliability** in order to implement **efficient operations** when using unmanned aircraft systems in the health field. These operations include planning, regulation compliance, drone and medical material preparation, and healthcare team coordination for an accurate and adequate answer.

The system needed for the operation is called **uncrewed aerial system (UAS)** and includes the drone, set of equipment and infrastructures formed by the aircraft, radio link, and ground infrastructure (aerials and ground station).

The use of drones in Spain has significantly grown in the past years. By the end of 2023, over 94,000 drone operators were registered, a 32% increase with regards to the previous year. This growth is greatly due to the implementation **of new European regulations that standardise drone use**, in force since January 2021. This legal framework has allowed greater flexibility and has encouraged both recreational operator registry as well as more complex operations that can be carried out easier in rural areas (3). Two main regulations exist (2):

- **Implementing regulation (EU) 2019/947 of the Commission**, 24th May 2019, regarding rules and procedures on unmanned aircrafts. This rule defines minimum requirements and key aspects to operate drones within Europe.

- **Delegated regulation (EU) 2019/945 of the Commission**, 12th March 2019, regarding unmanned aircraft systems and third country operators for unmanned aircraft systems. This rule provides specific technical requirements for drones within Europe.

Furthermore, Implementing regulations (EU) 2021/664, 2021/665, and 2021/666 regulate U-space.

The concept U-space refers to the set of specific systems, services, and procedures designed to allow safe, efficient, and affordable access to UAS operation airspace (4).

For more information on drones and context, you can check the [Report on Incorporating Drones into Healthcare \(2\)](#) out, published on TIC Salut Social Foundation's website.

3. State of the art



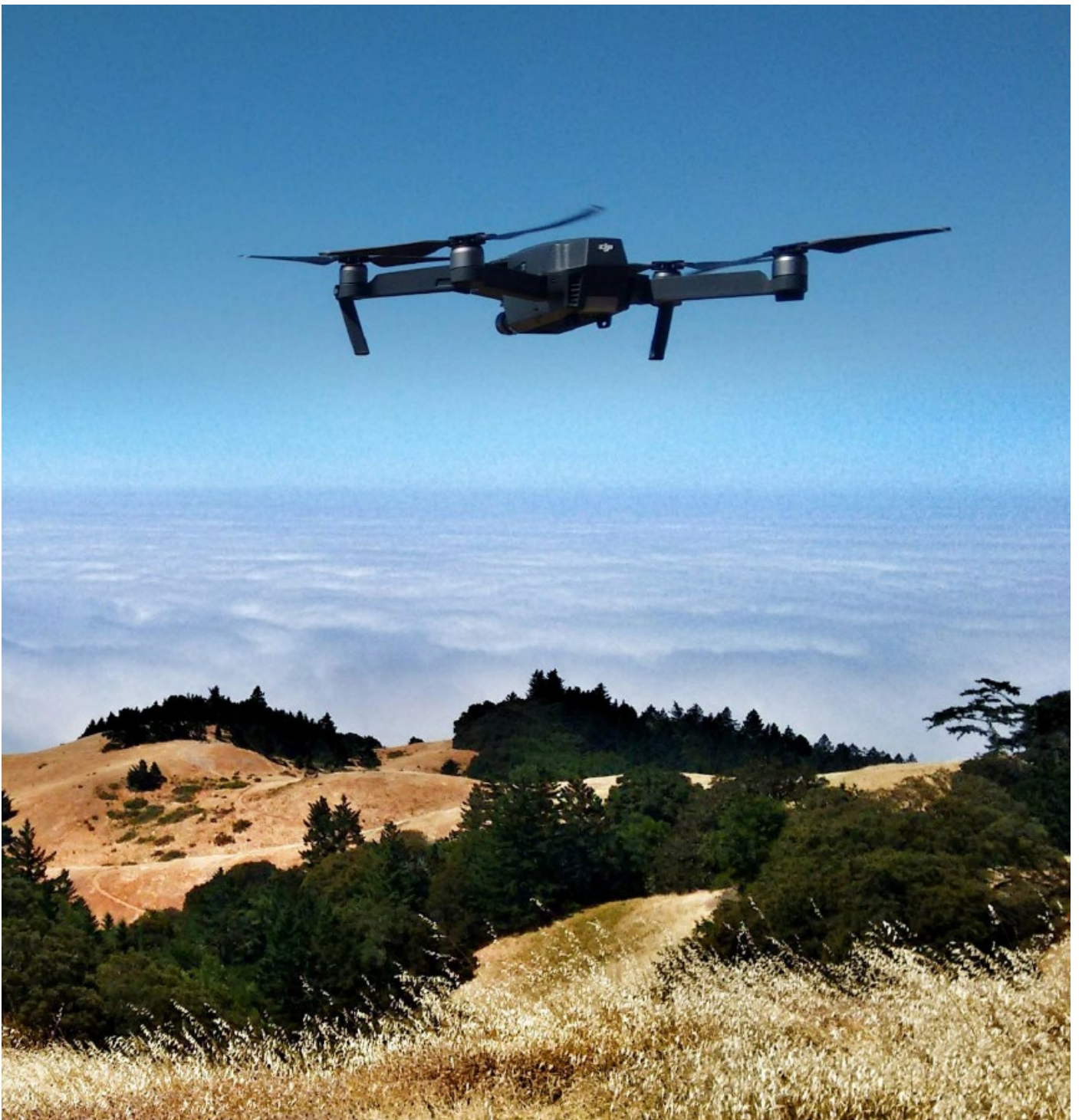
3.1. Catalanian
Healthcare System



3.2. Other experiences

State of the art drone projects applicable to healthcare reflect an accelerated technological and operational evolution in the last years propelled by needs to improve efficiency and accessibility to health services.

Projects stand out since **public institutions, technology companies, and health organisations collaborate and develop drone use models** with the goal of creating autonomous, safe, and efficient transport systems.



3.1. Catalan healthcare system experiences

As part of an initiative led by the Hospital of Olot, on May 3, 2023, a **one-day pilot test** was successfully carried out to transport biological samples by drone from a primary care center to the Hospital of Olot (5). The objective was to validate whether transport was feasible and whether

the samples would arrive in good condition.

The results were satisfactory, showing a 43% reduction in transport time, preservation of transport quality in terms of temperature control and vibration, and an 80.4% reduction in

CO² emissions. This pilot test paved the way for a **longer proof-of-concept study** to more thoroughly assess the efficiency and usefulness of this type of transport.

3.2. Other experiences

Various tests that involve biological sample transport using drones have been developed on both national and European levels. Some of which were the transport of critical samples during 2020 from 13 medical centres and hospitals to an analysis laboratory in Berlin. The German Federal Aviation Office authorised in 2023 a drone delivery platform for

beyond visual line of sight flights (2).

Another successful example was the dispatch of blood using drones in Rwanda. This circuit of care allows professionals to enter blood requests from the national centre for transfusions via mobile phone text message (2).

For more information on **worldwide healthcare** experiences using drones, please check the [Report on Incorporating Drones into Healthcare \(2\) out, written by TIC Salut Social Foundation.](#)



4. Methodology



4.1. Requirement analysis

4.1.1. Environment specifications

4.1.2. Drone type

4.1.3. Biological sample transport



4.2. Piloting design

4.2.1. Flight operative

4.2.2. Care flow

4.2.3. Indicators



4.3. Evaluation model

4.3.1. Logistics

4.3.2. Usability

4.3.3. Sample quality

4.3.4. Economic and environmental impact

The methodology to develop and implement the project included a number of structured phases to guarantee the project was **viable, safe, and adequately** met identified needs.

This methodology covers the analysis of necessary requirements, piloting design, and evaluation model **in the aim to guarantee the correct unfolding of transport routes and a precise evaluation of obtained results during the project.**



4.1. Requirement analysis

Environment specifications surrounding piloting centres, the type of

suitable drone, and necessary requirements to transport and analyse

correctly the blood samples were reviewed.

4.1.1. Environment specifications

The characteristics of the environment were studied in **three phases**: first, the area around the Hospital of Olot was analyzed and, subsequently, the surroundings of Vall d'en Bas, where the CAP Vall d'en Bas is located.

The Hospital of Olot and Comarcal de la Garrotxa is located in the city of Olot, the capital of the Garrotxa region, in the province of Girona, Catalonia. The hospital is situated on the outskirts of the city, in the Sant Jaume neighborhood, in an accessible area that is removed from the urban center. This location provides a quieter and less congested setting, improving

accessibility for both patients and emergency vehicles.

The hospital's surroundings are characterized by their proximity to the Garrotxa Volcanic Zone Natural Park, a region known for its volcanic landscapes and rich natural environment. This location offers green and natural surroundings, with views of the Santa Margarida and Croscat volcanoes, providing patients and staff with a visually pleasant and healthy environment.

From a logistical standpoint, the Hospital of Olot is well connected by

road, with access to the C-37 highway and the N-260 road, facilitating travel both from the city of Olot itself and from nearby towns. This strategic location enables the hospital to provide healthcare services not only to the city of Olot but also to other municipalities in the Garrotxa region. It is particularly important for serving rural and hard-to-reach areas, where drones could have a significant impact in terms **of fast and efficient medical transport.**



Figura 2. Garrotxa Region. (1. Hospital of Olot – 2. CAP Vall d'en Bas)

The **Primary Healthcare Centre Vall d'en Bas** belongs to the valley with the same name. The Vall d'en Bas (Bas Valley) is south-north facing, from the Coll d'Uria in the south, following the direction marked by the C-153 road until La Serra industrial estate parallel to the Fluvià river and the villages of El Mallol and La Pinya, until the northern part where the road splits onto Riudaura to the west and Olot to

the east. The eastern side surrounds La Garrotxa Volcanic Zone Natural Park alongside the Corb mountain range, the Racó volcano, the Pedra Tosca park, and Fluvià and Riudaura riverbanks.

On the other side, the western area limits to the south with Llancers and Puigsacalm mountain ranges. The C-37 road passes through these

two geographical features, the main access to the county from the south-west tunnel exit at Bracons. From this viewpoint, the valley advances up north enclosing the Magdalena massif and the Freixenal mountain range.

In the following image, we can see Olot Hospital in regards to the Sant Esteve d'en Bas Primary Healthcare Centre.

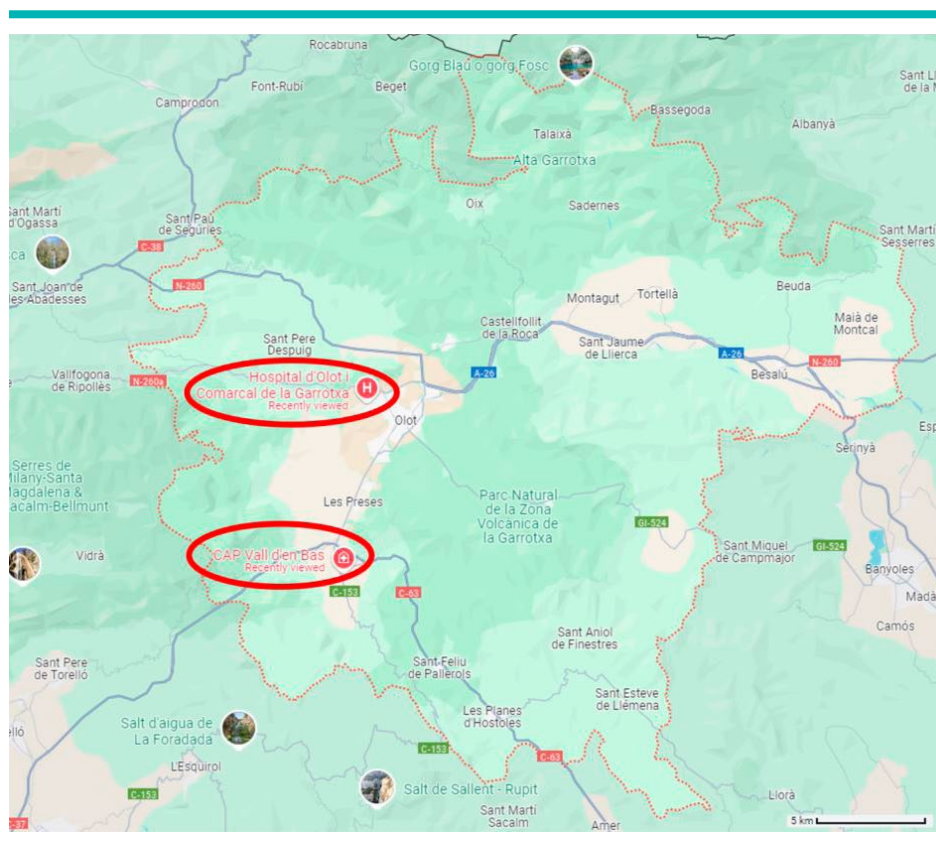


Figure 3. Google Maps screenshot of the selected centers in the Garrotxa region and Vall d'en Bas

The Vall d'en Bas Primary Care Center (CAP Vall d'en Bas), located in Sant Esteve d'en Bas, is situated in the southeastern area of the town, less than 150 meters from the C-153 regional road, which marks the western boundary of the municipality.

The center has an adjacent green area. Figure 4 shows a map of Sant Esteve d'en Bas, where the location of the primary care center can be observed. Its **location** facilitates obtaining flight permits, and the adjacent green area makes landing easier.

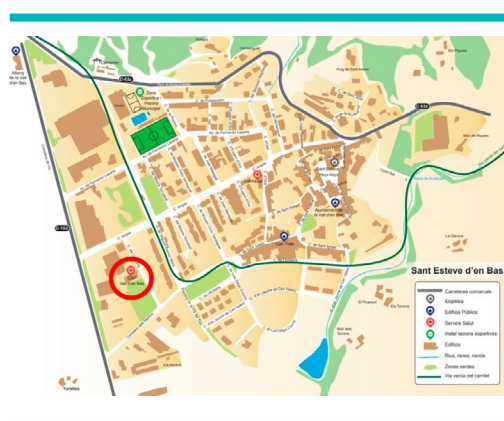


Figure 4. Municipal map of Sant Esteve d'en Bas and the Vall d'en Bas Primary Care Center (red circle) (7)

4.1.2. Drone types

The selected drone model had to comply with project requirements, **guaranteeing technical and logistical needs** and a number

of flight specifications to fly in the selected area.

The selected drone is **electric VTOL**

(vertical take-off and landing) fed with electricity. So, it is called **eVTOL**.



Figure 5. Drone eVTOL used for the project alongside its base

VTOL's ability to take off and land vertically allow for operations in **reduced spaces** (only 5 metres in diameter), even though not originally destined to this end. This causes them to be **more adaptable to taking off and landing in basic healthcare areas and the Hospital**, thus being closer to delivery and loading zones.

The drone model used in this project is the **Eiger by Rigittech**. This drone has a length of 166 cm and a wingspan of 240 cm, with an empty weight of 10.5 kg. It features a 15-liter **cargo compartment** when using a single box, or alternatively two 6-liter compartments. The maximum payload

capacity is 2.5 kg.

The drone has a flight range of 80 km. In this project, the drone operation has been calculated for approximately 20 km, meaning it adequately meets the established requirements.

It operates using **electric batteries**, which helps reduce pollutant emissions and therefore minimizes environmental impact.

This **eVTOL drone is equipped with wings and two sets of propellers**. During the vertical flight phase (takeoff and landing), it uses four propellers,

allowing it to reach an approximate speed of 12 km/h until the desired altitude is achieved. Once this altitude is reached, it switches to horizontal flight mode. Using its wings and an additional propeller, the drone can fly faster and more efficiently, reaching a cruising speed of 100 km/h. During horizontal flight, it demonstrates high energy efficiency.

4.1.3. Biological sample transport

To carry out the transport of samples, the **current regulations governing transportation**, packaging, and required conditions were taken into account. In addition, the necessary **laboratory** variables were defined to assess the quality of the transported samples.

Blood samples are categorized as **B Category** substances as specified in the **UN 3373 regulation**, as indicated on pages 232 and 233 of the 2023 European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) (8).

Therefore, according to this classification, the packaging used must comply with **Packing Instruction P650 (9)**.

This instruction establishes that sample packaging must consist of **three distinct layers**:



Primary packaging:

In the event of liquid samples, primary packaging shall be leak-proof and under 1 l in capacity. Additionally, the instruction indicates that multiple primary receptacles must be separated, so cannot enter into contact.



Secondary packaging:

Must be leak-proof and lined with absorbent material.



Outer rigid packaging:

This can contain up to 4 l, considering dry ice, ice, or ice packs.

To evaluate the **quality of the transported samples**, temperature and impact sensors were used for both drone and van transport.

To assess impact, it was defined that the sensor would trigger an alert if it detected more than three impacts. Regarding temperature, a range between 5 and 20 °C was established as appropriate for blood transport. If the values exceeded this range, the sensor would also generate an alert. **In the absence of alerts during transport, the transport conditions would be considered adequate.**

Finally, to evaluate the quality of the transported samples, it was decided to compare the **results of the following laboratory variables**: hemolysis index and concentrations of **potassium, lactate dehydrogenase**

(LDH), and glucose. These variables make it possible to detect potential alterations during transport, considering that increased hemolysis may lead to elevated potassium and LDH levels.

Additionally, the **reference ranges** (values considered normal in the absence of physiological alterations) for each variable were taken into account to assess whether the obtained values remained within normal limits in both types of transport.

The reference ranges are:



Haemolysis index:

0 - 50 (0 represents the absence of haemolysis, the optimal value)



Potassium concentration:

3.4 - 5 mmol/l*



LDH concentration:

60 - 160 U/L



Potassium concentration:

70 - 100 mg/dL

4.2. Piloting design

Once requirements were analysed, the necessary **flight operative design** for drone transport, **the transport care**

flow, and indicator definition for route evaluation were conducted.

4.2.1. Flight operative

Defining the flight operative implies **two parts**: defining drone trip and then take-off and landing areas.

The trip starts at the **Primary Healthcare Centre Vall d'en Bas** and ends at Olot Hospital.

Location for both piloting centres is shown in the following image:

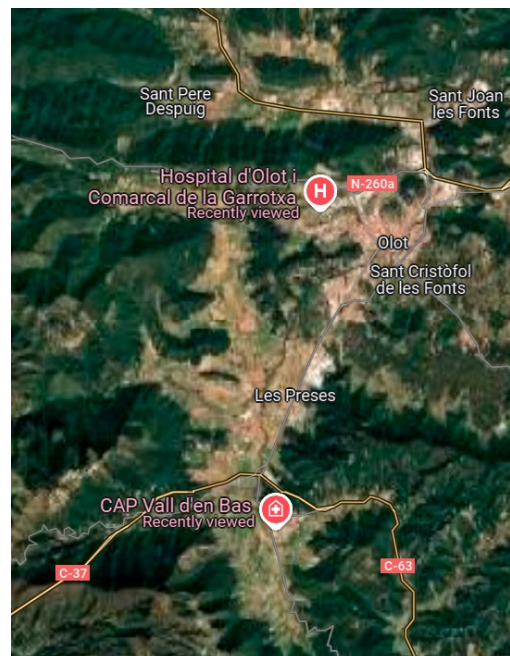


Figure 6. Selected piloting centres (Google Maps screenshot).

The **trajectory was defined** under the operational framework covered by the Light **UAS Operator Certificate (LUC)**¹(10) held by the company operating the flight. This certification allows the operator to self-authorize drone flights provided that **certain requirements are met regarding population density**, the flight area,

and the characteristics of the drone used.

The trajectory was divided into **two segments**, taking into account the characteristics of the area and, in particular, the presence of the Natural Park of the Volcanic Zone of La Garrotxa. Figure 7 shows the defined

flight area, where the option was taken to minimize the distance flown within the Natural Park territory (the brown-shaded area on the right side of the image). The figure corresponds to a screenshot from the **ENAIRES Drones simulator** (11), taken on May 28, 2024, showing the planned flight route.

¹ **LUC** (Light UAS Operator Certificate) is a certificate issued by the civil aviation authority that authorises an organisation to operate drones inside of the European Union with certain autonomy and flexibility. This certificate is issued by the European Aviation Safety Agency (EASA) and allows drone operators to perform medium and high-risk operations without the need to request authorisation before each flight, provided standards and procedures established in LUC are followed.

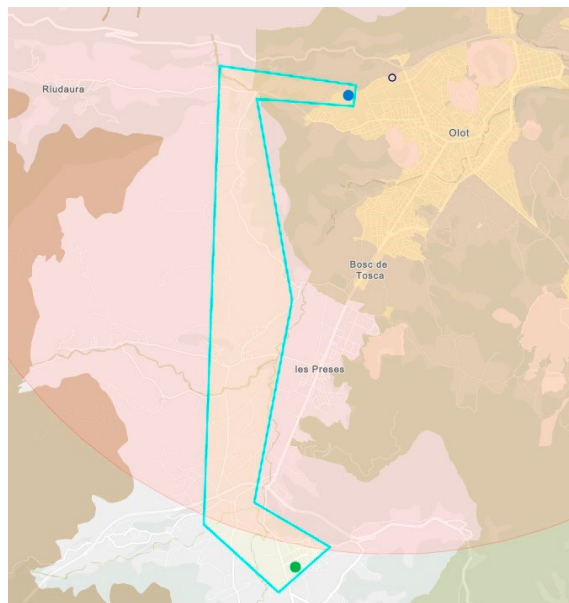


Figure 7. Flight zone from Primary Healthcare Centre Vall d'en Bas (green) until Olot Hospital (blue)

In the first segment of the route, from takeoff at CAP Vall d'en Bas, a northbound path was defined along the central area of the valley, thereby avoiding the Natural Park. This area, with a high presence of farmland, made it possible to reduce risks both on the ground and in the air, minimizing the impact on protected areas and other airspaces prioritized for use by other aircraft.

In addition, the orographic relief of the area allowed the flight to be maintained at an altitude below 120 meters above ground level (AGL). This heading was maintained until reaching the junction of the GIV-5224 road with the GIP-5233 road (Riudaura–Olot road).

to pass through Natural Park territory from the La Pinya sector, as shown in the following image. The areas of the Montolivet volcano and Muntanya Pelada were avoided, as they are considered zones of high faunal interest.

The second segment of the route, from the junction to the landing area at the Hospital of Olot, inevitably had

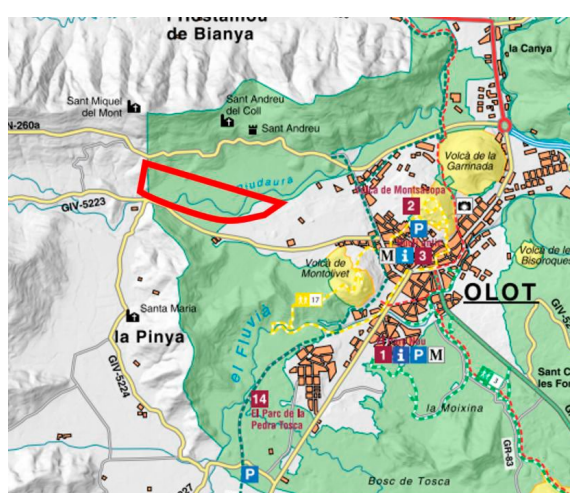


Figure 8. Flight area inside of La Garrotxa Volcanic Zone Natural Park

In addition to reducing the distance flown within the Natural Park, and with the aim of minimizing the drone's impact on local wildlife, it was decided to limit the number of flight operation days to a total of five over the two-week period.

Accordingly, **five round-trip flights were defined**, each with a maximum duration of 10 minutes, of which no more than 1.5 minutes were spent

within the territory of the Natural Park.

Finally, **the takeoff and landing zones were established at the respective facilities**. For takeoff at CAP Vall d'en Bas, an area was designated on a plot of land adjacent to the center, where the takeoff support equipment was deployed.

At the Hospital of Olot, two areas were defined (the loading dock and

an adjacent area next to the loading dock), previously validated for safety, operational considerations (vehicle and pedestrian traffic), and GPS connectivity. These zones were selected as close as possible to the Hospital's analysis laboratory (approximately 50 meters in the case of the area adjacent to the loading dock).



Figure 9. Olot Hospital drone landing area

4.2.2. Care flow

A **clinical workflow** was defined to operationalize the transport process, consisting of **four distinct phases**, each involving different **professionals and locations**.

1. Collection of the samples at CAP Vall d'en Bas
2. Transport of the samples from CAP Vall d'en Bas to the Hospital of Olot
3. Receipt and analysis of the samples at the Hospital of Olot
4. Return of the drone to CAP Vall d'en Bas

In order to carry out the **comparison between drone and van transport**, it was decided that two blood tubes would be drawn from all patients participating in the project. All samples collected under ordinary conditions

would be transported by drone and, additionally, an **extra blood tube would** be drawn and transported following the usual logistics by van. In this way, the results of the blood sample transport could be compared.

The sample collection phase at CAP Vall d'en Bas was defined by the nursing staff of the center and was carried out as follows:



Figure 10. Care flow at Primary Healthcare Centre Vall d'en Bas

First, it was agreed that [1] patients with a scheduled blood test who attended the CAP on any of the days of the proof of concept [2] would be seen at their usual appointment time.

These patients [3] were informed about the project and those who voluntarily agreed to participate were provided with an informed consent document to sign.

[4] Blood samples were then drawn from participating patients under the same standard conditions: the samples that would be transported by drone and, additionally, one extra blood tube to be transported by van. The tubes were labeled according to the usual procedure, distinguishing between both transport methods. Non-participating patients did not have the additional tube drawn. For both transport methods, blood samples were collected in individual

10 ml tubes. Once the samples had been collected and labeled [5], they were prepared for transport by drone and van using the required regulatory packaging. The tubes were placed in racks, and the entire set was inserted into a waterproof plastic bag. They were then placed inside passive cooling containers with gel packs. The tubes designated for van transport were prepared following the usual workflow. In both transport methods, a temperature sensor and an impact sensor were included inside the bags.

Finally, [6] the nursing staff handed over the properly packaged samples to the drone operator for air transport and, separately, to the person responsible for van transport.

Prior to the proof of concept, a brief training session was provided

to the professionals involved in the operational procedures for the handover and reception of the samples transported by drone.

The transport of samples by drone was carried out by the operator following the defined route and the schedule established in the clinical workflow. The drone took off immediately after the blood collection process was completed. Transport by van followed the usual route and timing.

The reception and analysis of the samples at the Hospital of Olot was defined by the laboratory and administrative staff of the center. For this project, it was necessary to add several steps to the standard clinical workflow.

The defined steps are detailed below.

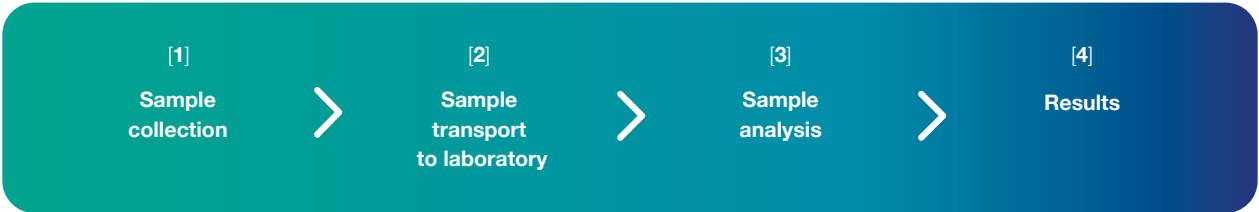


Figure 11. Olot Hospital care flow

Once the drone landed at the hospital and the operator unloaded the samples, [1] laboratory personnel would pick the biological samples up from the drone and [2] carry them by foot to the laboratory.

Once at the laboratory, [3] both drone

and van samples would be analysed following standard procedures and, [4] in the end, results from the blood samples would be collected for selected laboratory variables.

Apart from the outbound trip from the Primary Healthcare Centre to the

hospital, the drone would also return to the base at Sant Esteve d'en Bas, from where it would leave the next day.

4.2.3. Indicators

A **set of indicators** were established to measure during flights in order to evaluate drone transport.

Three different dimensions were determined:

Logistics and usability:

- Transport vehicle departure time (drone and van)
- Transport vehicle arrival time (drone and van)
- Sample arrival time at laboratory (drone)
- Healthcare personnel dedication time (drone)
- SUS scale (System Usability Scale) (drone)

Sample quality:

- Blood haemolysis index
- Blood potassium concentration (mmol/l)
- Blood Lactate Dehydrogenase (LDH) concentration (U/l)
- Blood glucose concentration (mg/dl)
- Number of collisions
- Temperature range

Economic and environmental impact:

- Healthcare personnel costs
- Flight personnel costs
- Service contracting costs
- CO² emissions (drone and van)

Regarding the **results for the logistics and usability dimension**, the staff responsible for the operation will record deliveries and operation times in an Excel table. In addition, a flight log will be maintained to document routes, flight times, and weather conditions.

The SUS scale will be collected through an online form accessible via computer and mobile devices. This form

will be completed by the healthcare professionals involved in the part of the clinical workflow that includes the drone operation, specifically those responsible for handing over and receiving the transported samples.

As for **sample quality**, laboratory professionals will analyze four laboratory indicators in the blood samples (hemolysis, potassium, LDH, and glucose) and will assess the data recorded by the sensors (impacts and temperature).

Finally, the necessary data will be collected to evaluate the costs and environmental impact of the two transport methods.

4.3. Evaluation model

To analyze the project indicators and evaluate the transport of samples by drone, different criteria and methods were used, **organized into four dimensions of indicators:**



Figure 12. Indicator dimensions

4.3.1. Logistics

The evaluation of logistics and operational performance is key to ensuring that unmanned aircraft systems implemented in healthcare projects operate efficiently, safely, and sustainably. This phase involves a detailed analysis of the drone system's capacity to meet the logistical requirements of the project and its integration with existing operational

processes within the healthcare system.

Initially, the travel **time for each transport day was calculated based on the departure and arrival times of each vehicle**. Subsequently, the time difference between **drone transport and road transport was calculated**. The mean and standard

In addition, the **percentage reduction in transport** time achieved with the drone was calculated based on the average time obtained for drone and van transport using the following expression:

Equation 1

$$\text{Reduced time (\%)} = \frac{\bar{t}_{\text{drone}} - \bar{t}_{\text{van}}}{\bar{t}_{\text{van}}} \cdot 100$$

Once the time reduction had been calculated, it was assessed whether the **sample values** followed a normal distribution using the **Shapiro-Wilk test**, with a 95% confidence level. If both samples met the normality criteria,

a parametric test was used; otherwise, a non-parametric test was applied. The paired-samples t-test was used as the parametric test, and the Wilcoxon signed-rank test as the non-parametric test. Both tests allow for the evaluation

of whether significant differences exist between the means, although the parametric test provides greater statistical reliability and robustness.

4.3.2. Usability

On the other hand, system usability was evaluated using **the SUS (System Usability Scale)** (see Annex I). This scale allows for the assessment of the **subjective usability** of a device or technological system. It consists of 10 questions answered using a **Likert scale** format.

The scale assigns a numerical value from 1 to 5 corresponding to the possible responses ("strongly disagree," "disagree," "neutral," "agree," and "strongly agree").

Based on these numerical scores, the total SUS score is calculated following the standard SUS scoring procedure.

1. The adjusted scores are calculated by subtracting 1 from the score of each odd-numbered question and subtracting each even-numbered question score from 5.
2. All adjusted scores are summed.
3. The total sum is multiplied by 2.5.

4.3.3. Sample quality

The **quality of the samples** transported by drone and by van was **evaluated based on transport sensor data and laboratory results**. Using the sensor data, it was verified whether temperature and impact levels remained within the appropriate ranges.

Regarding laboratory results, the

mean and standard deviation of each variable (hemolysis index –HI– and potassium, LDH, and glucose concentrations) were first calculated for all blood samples transported by drone and by van.

Subsequently, the percentage difference between the results obtained with the drone and those

obtained with the van was calculated (**Equation 2**). To assess the statistical significance of the difference between both transport methods, the observed difference was normalized using the reference range (**Equation 3**).

Equation 2

$$\text{Difference (\% change regarding van)} = \frac{x_{van} - x_{drone}}{x_{van}} \cdot 100$$

Equation 3

$$\text{Difference (\% normalised with = reference range)} = \frac{x_{van} - x_{drone}}{\max_{rang} - \min_{rang}} \cdot 100$$

This analysis made it possible to determine whether apparently small differences were clinically relevant, given that the value ranges of some variables are narrow. The analysis was further strengthened statistically a paired-samples t-test, which allowed for the assessment of whether the means of each variable for each transport method showed statistically significant differences, with a 95% confidence interval.

To analyze each laboratory variable in greater detail and assess the agreement between the two transport methods, **Bland–Altman** plots were generated for each variable. These plots display the **difference between the values obtained** for each patient by drone and by van against the mean of both values.

Each plot shows the **mean difference** ($\bar{x}$), along with the upper and lower limits of the 95% confidence interval—calculated as the mean difference $\pm$

1.96 standard deviations—as well as the trend line or linear regression. **If both methods were fully equivalent, the differences would be minimal and the data points would form a horizontal line with low dispersion.**

Finally, to evaluate potential correlations between the hemolysis index and the other variables, **three Pearson correlation tests** (potassium–HI, LDH–HI, and glucose–HI) were performed using the differences observed for each variable.

4.3.4. Economic and environmental impact

To evaluate the **costs of the pilot** operation, two main components were considered: on the one hand, the cost of the **drone transport service**, and

on the other, the **cost of the CAP nursing staff** responsible for handing over the samples, as well as the Hospital staff who received them and

transported them to the laboratory. Regarding the transport service, its cost was calculated as the sum of **three categories**:

- **UAS costs:** drone and associated equipment costs.
- **Personnel costs:** costs for personnel to operate the drone.
- **Indirect costs:** costs to establish routes (regulation review, environment analysis, etc.) and others.

To calculate the **environmental impact** of both routes, the emissions generated during transport were assessed. Emissions associated with the manufacturing and maintenance of the drone and the van were excluded

from the analysis.

For the calculation of **CO₂ emissions** by van, a standard van and **the shortest possible route** were considered. This route runs via the

C-152 road, covering a distance of 10.5 km. The figure below shows the selected route in dark blue.

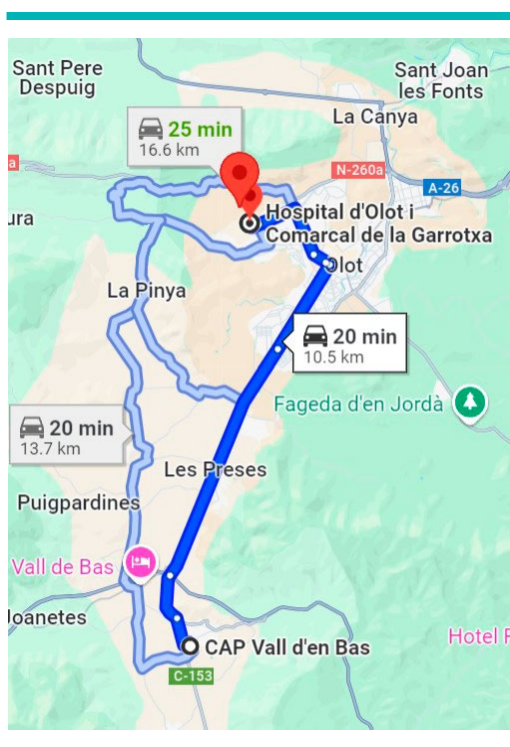


Figure 13. Road routes between Primary Healthcare Centre Sant Esteve d'en Bas and Olot Hospital

Van emissions were calculated using the CeroCO carbon calculator (11). For greater accuracy, the distance corresponding to 100 trips was entered into the calculator, and the resulting CO² emissions were then divided by 100.

On the other hand, to calculate the drone's emissions per trip, the most recent available electricity emission factor was used. This value, dated April 25, 2024, is 260 g CO² eq/kWh and represents the emissions associated with generating one kWh

of electrical energy in Spain (12). This value was multiplied by the drone's electricity consumption, calculated using the following expression:

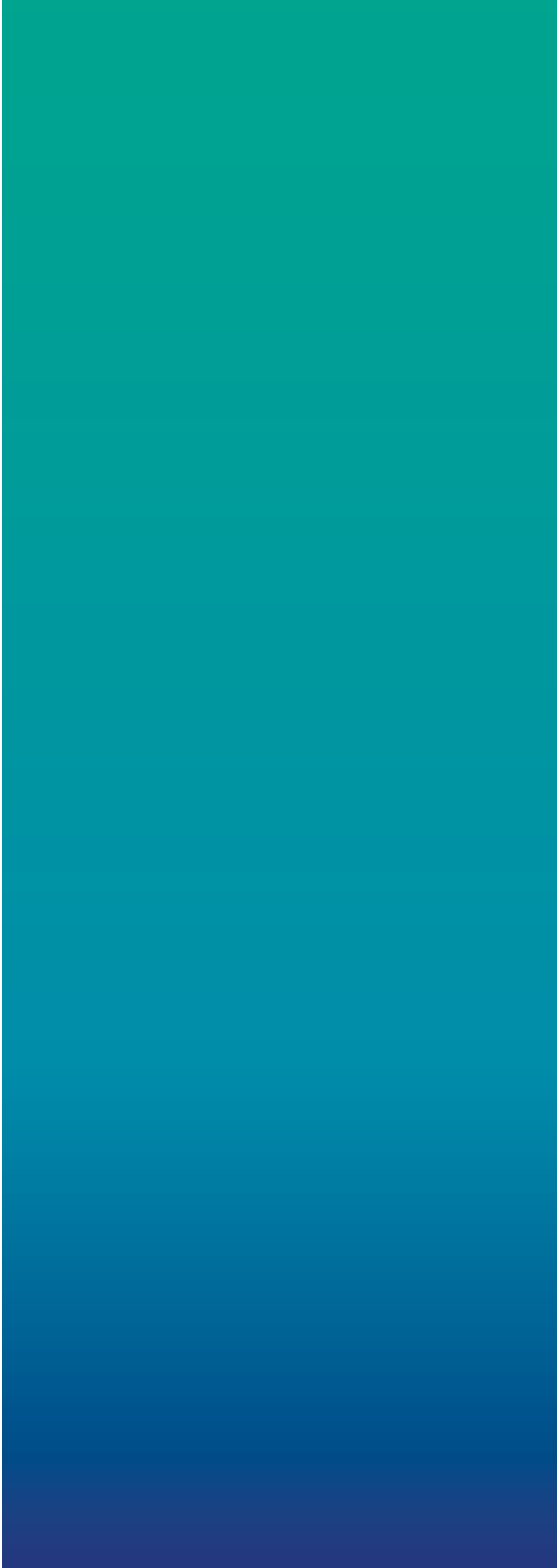
Equation 4

$$\text{Drone energy}_{Kwh} = \text{Energy consumed (Ah)} \cdot \text{Voltage Batteries (V)} \cdot \bar{t}_{\text{Drone flight segment}}$$

The results are expressed in grams of carbon dioxide equivalent

(g CO²eq), the standard unit for measuring greenhouse gas emissions (13).

5. Piloting



Piloting took place between the second and third weeks of June 2024. Since the Primary Healthcare Centre Vall d'en Bas only draws blood some days each week (Mondays, Wednesdays, Thursdays, and Fridays), the five piloting days were divided between those days. The concept test was carried out on the **12th, 14th, 17th, 19th, and 21st of June 2024**.

There were no incidents while executing the designed and programmed operation, and the different teams participated as planned.

9:00 and 12:00 were the hours defined for the flights **in order to have margin should the weather or technical conditions be unfavourable**.

The following weather conditions were logged during operation timetables:

Table 1. Weather conditions at Bas Valley within timetable operation ranges

Day	12/06/2024	14/06/2024	17/06/2024	19/06/2024	21/06/2024
Flight time slot	10:00- 10:30	9.30 - 10:00	10.30 - 11:00	9.30 - 10:00	11.00 - 11:30
Pictogram					
Estació Vall d'en Bas (W9)	Average temperature: 14,2 °C - 14,5 °C Relative humidity: 91-89 % Average wind speed at 2 metres 2,4 m/s - 2,3 m/s Maximum wind gusts: 3,8 m/s - 3,5 m/s	Average temperature: 19,8 °C - 20,5 °C Relative humidity: 67-65 % Average wind speed at 2 metres 3,1 m/s - 2,9 m/s Maximum wind gusts: 6,3 m/s - 6,6 m/s	Average temperature: 25,1 °C - 25,7 °C Relative humidity: 52-51 % Average wind speed at 2 metres 0,8 m/s - 1,5 m/s Maximum wind gusts: 2,4 m/s - 3,5 m/s	Average temperature: 21,3 °C - 21,6 °C Relative humidity: 77-78 % Average wind speed at 2 metres 1,4 m/s - 1,7 m/s Maximum wind gusts: 3 m/s - 3,2 m/s	Average temperature: 20 °C - 21,1 °C Relative humidity: 70-67 % Average wind speed at 2 metres 1,7 m/s - 1,9 m/s Maximum wind gusts: 3,6 m/s - 3,4 m/s

Table 2. Olot Station weather during operation time slots.

Day	12/06/2024	14/06/2024	17/06/2024	19/06/2024	21/06/2024
Flight time slot	10:00- 10:30	9.30 - 10:00	10.30 - 11:00	9.30 - 10:00	11.00 - 11:30
Pictogram					
Olot Station (YB)	Average temperature: 13,8 °C - 13,9 °C Relative humidity: 95-96 % Average wind speed at 10 metres 2,4 m/s - 1,2 m/s Maximum wind gusts: 4,4 m/s - 3 m/s Rain: 2,2 mm - 0,2 mm	Average temperature: 21,4 °C - 21,9 °C Relative humidity: 58 % Average wind speed at 10 metres 2 m/s - 3,3 m/s Maximum wind gusts: 5,4 m/s - 6,9 m/s	Average temperature: 25,1 °C - 25,4 °C Relative humidity: 56-57 % Average wind speed at 10 metres 4,1 m/s - 4 m/s Maximum wind gusts: 7,1 m/s - 6,9 m/s	Average temperature: 21 °C - 22,1 °C Relative humidity: 77-74 % Average wind speed at 10 metres 3,4 m/s - 2,4 m/s Maximum wind gusts: 5,3 m/s - 4,7 m/s Mist at 9:00h	Average temperature: 21,5 °C - 22,5 °C Relative humidity: 61-57 % Average wind speed at 10 metres 1,4 m/s - 1,3 m/s Maximum wind gusts: 4,1 m/s - 3,9 m/s

6. Evaluation of results



6.1. Logistics



6.2. Usability



6.3. Sample quality

6.3.1. Haemolysis index

6.3.2. Potassium concentration

6.3.3. Lactate Dehydrogenase (LDH) concentration

6.3.4. Glucose concentration

6.3.5. Correlations between indicators



6.4. Economic and environmental impact

6.4.1. Costs

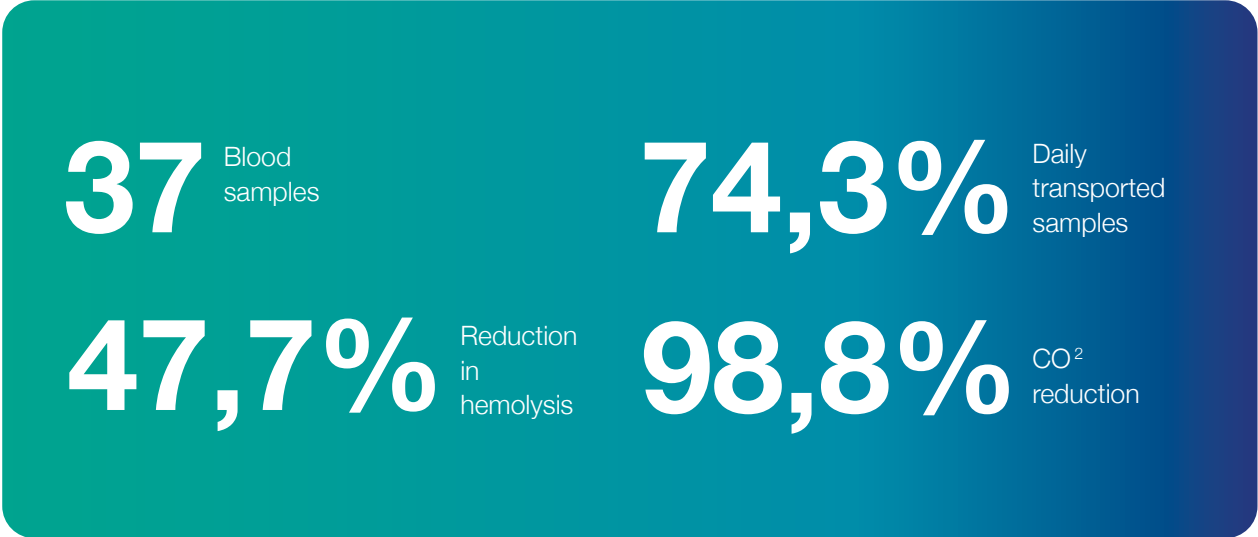
6.4.2. Environmental impact

The results obtained from the project evaluation are presented below. First, an overall view of the results is provided, followed by a detailed explanation of the four dimensions of the indicators.

The transport of samples by drone

was successfully carried out in all five programs. A total of 37 samples were transported, and transport time was reduced by 74.3% compared to van transport. The hemolysis rate of the samples decreased by 47.7%. The drone's loading system obtained a score of 74 points on the SUS scale,

and CO² emissions per trip with the drone were 98.8% lower than with the van.



An average of 7.4 samples were transported per day, with a

maximum of 12 per day and a minimum of 4. The statistics for each

day are shown below:

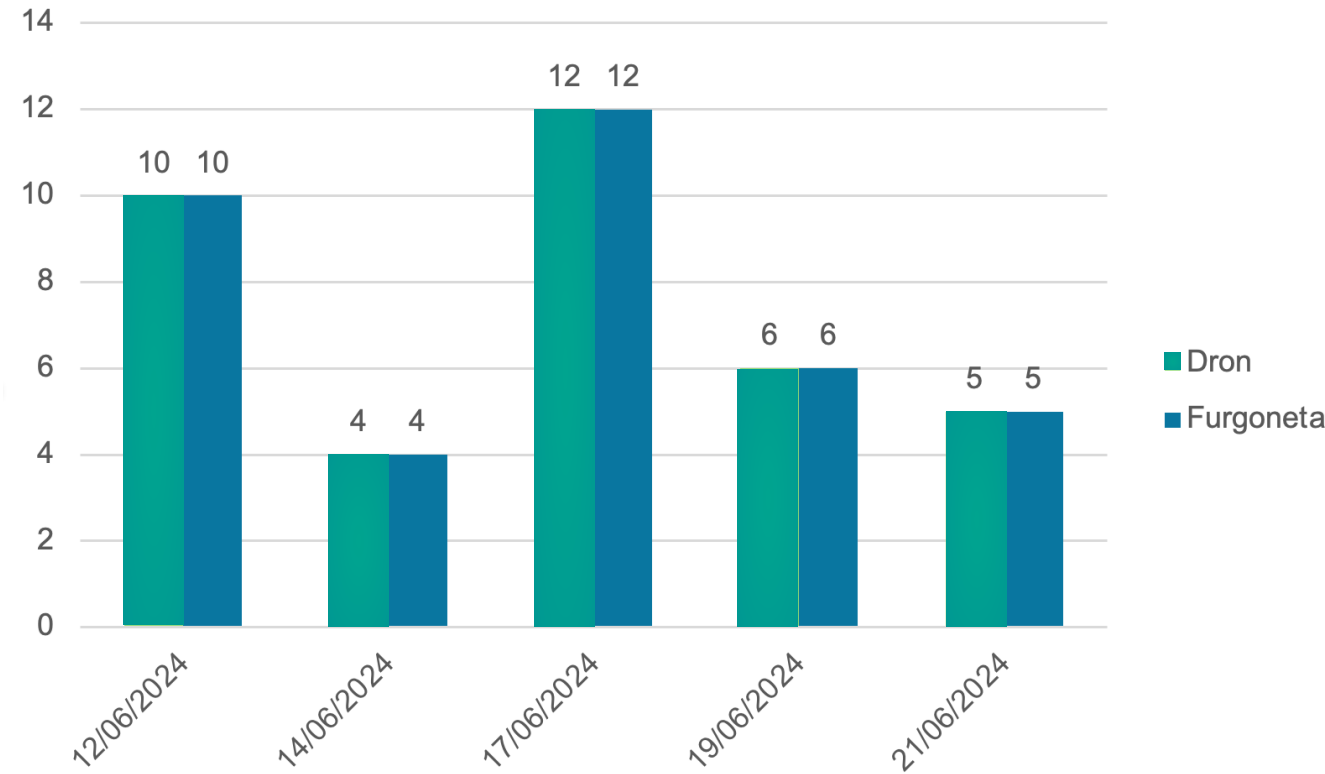


Figura 14. Number and type of biological samples transported by drone and van

Regarding the difference in departure time between the drone and the van, the van arrives each day within the agreed time window, whereas the drone departed from the CAP as soon as the blood draws were completed. As a result, the samples transported by drone had a shorter waiting time at the CAP, **which reduced the potential degradation of the samples.**

Taula 3. Transport times by drone and van

Data	Drone		Van	
	Departure time	Arrival time	Departure time	Arrival time
12/6/2024	10:11:01	10:18:58	10:26:00	11:12:00
14/6/2024	09:49:00	09:56:03	10:40:00	11:04:00
17/6/2024	10:54:12	11:01:26	10:50:00	11:19:00
19/6/2024	09:43:39	09:51:32	10:38:00	10:56:00
21/6/2024	11:15:00	11:22:36	10:29:00	10:59:00

6.1. Logistics

The **transport times** by drone and van are shown below, as well as the **time difference** between both modes of transport:

Table 4. Transport times by drone and van

Data	Drone	Van	Difference
12/6/2024	7 min 57 s	46 min	38 min 3 s
14/6/2024	7 min 3 s	24 min	16 min 57 s
17/6/2024	7 min 14 s	29 min	21 min 46 s
19/6/2024	7 min 53 s	18 min	10 min 7 s
21/6/2024	7 min 36 s	30 min	24 min 24 s
Average and standard diversion	7 min 32 s ± 23 s	29 min 24 s ± 10 min 24 s	21 min 52 s ± 10 min 1 s

The **mean duration** of the trips carried out by drone is 7 min 32 s $\pm$ 23 s, while trips by van last on average 29 min 24 s $\pm$ 10 min 24 s. Therefore, transport time by drone was reduced by **74.3%** compared to the van. In other words, drone transport time

accounted for approximately one **quarter of the van transport time.**

The t-test performed shows that the difference between the two modes of transport is statistically significant ($p\text{-value} = 0.00901 < 0.05$). In

addition, road transport times show greater variability compared to drone transport times.

74,3% Number of samples transported

6.2. Usability

As far as **usability** is concerned by including drone technology in the care process, the average score given by

professionals on the SUS scale was of 74 points over a maximum of 100.

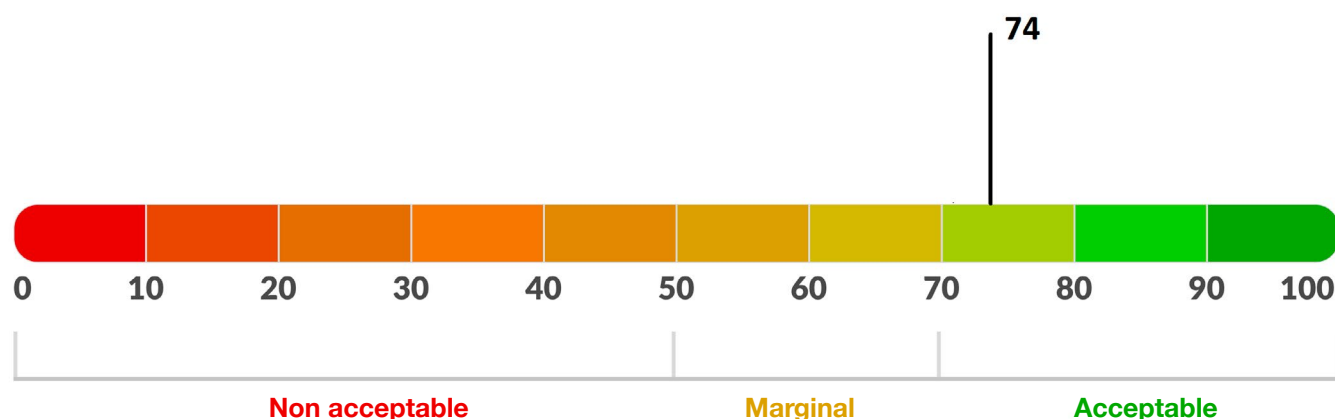


Figure 15. SUS scoring

This scoring is slightly over the threshold of **68-70, which would indicate correct usability during the drone transport**, loading, and unloading process.

When asked regarding usability, professionals believe drone technology is **100% easy to use**. They also **favour its use**, and the majority do not consider it to be a complicated

technology (67%).

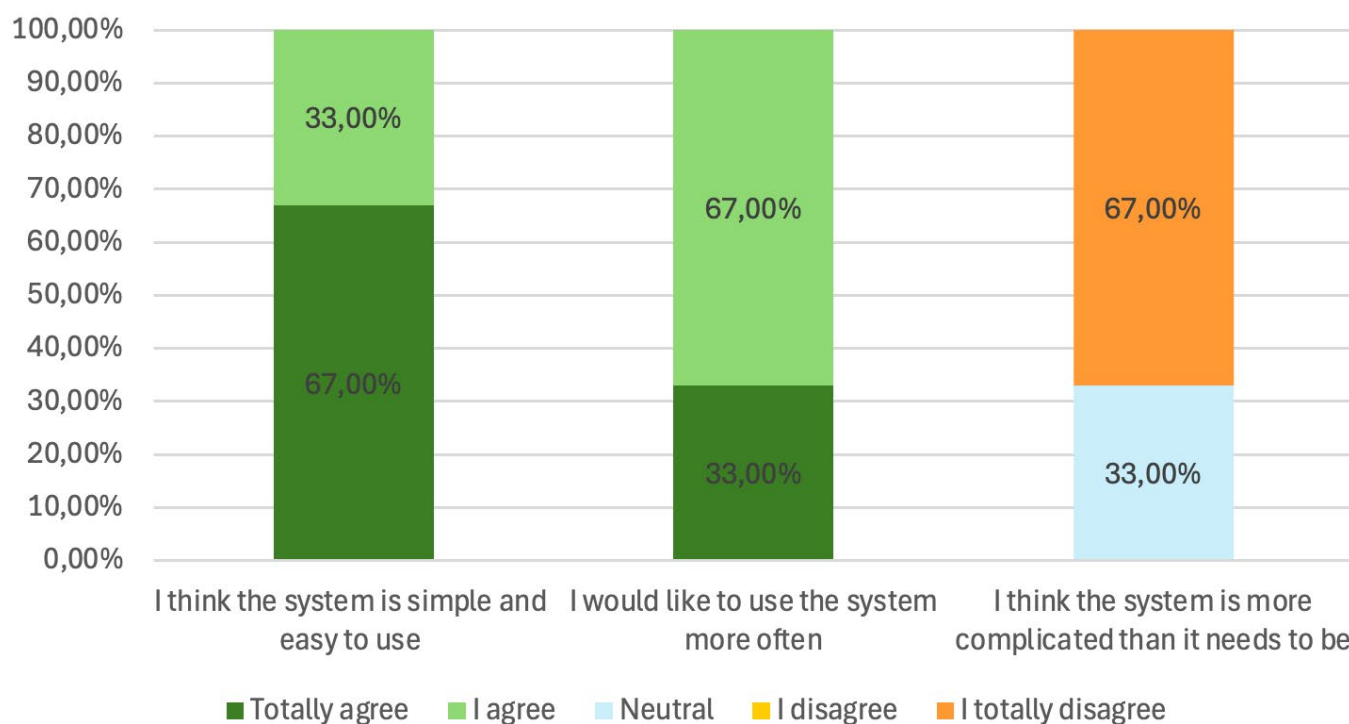


Figure 16. SUS Scale Results – Usability

From a competency perspective, professionals believe that most people can learn to use this type of technology, although there are

differing opinions regarding the need for technical support (33% agree, 33% are neutral, and 33% disagree).

The use of drone technology is not considered complex, nor is it perceived as requiring a long learning period.

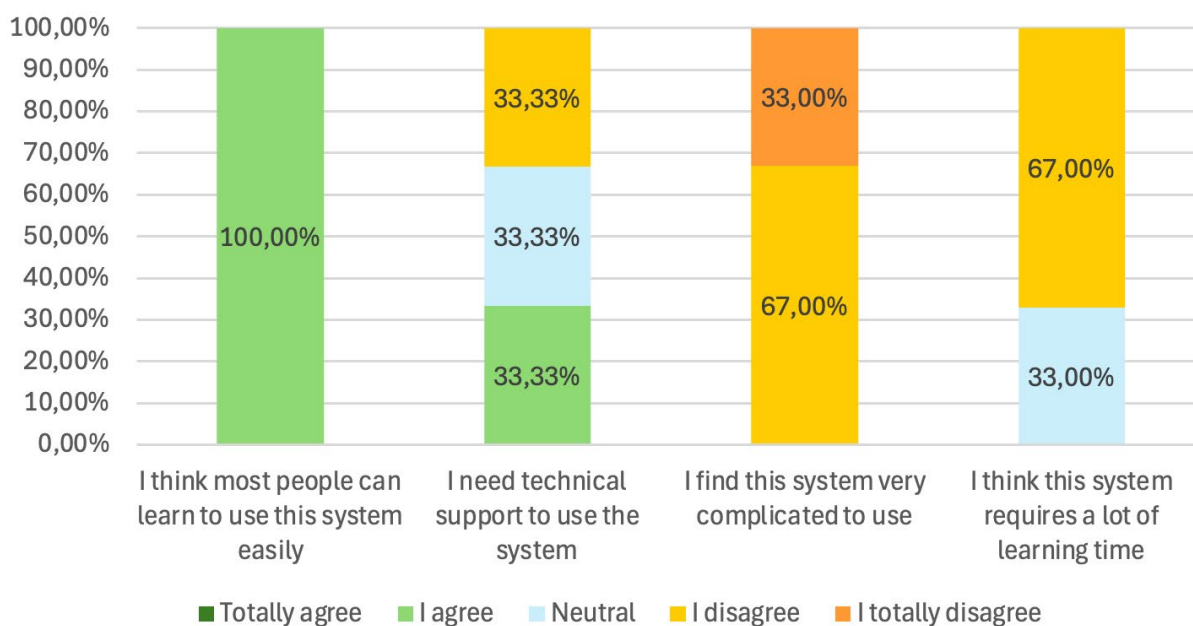


Figure 17. SUS Scale Results on Professional Competencies

In the evaluation of the process, professionals report **that there are no integration issues**, with 33% indicating that it functions properly and

is integrated into the care process. They also report that the incorporation of drone technology has not

generated incidents or irregularities in the process.

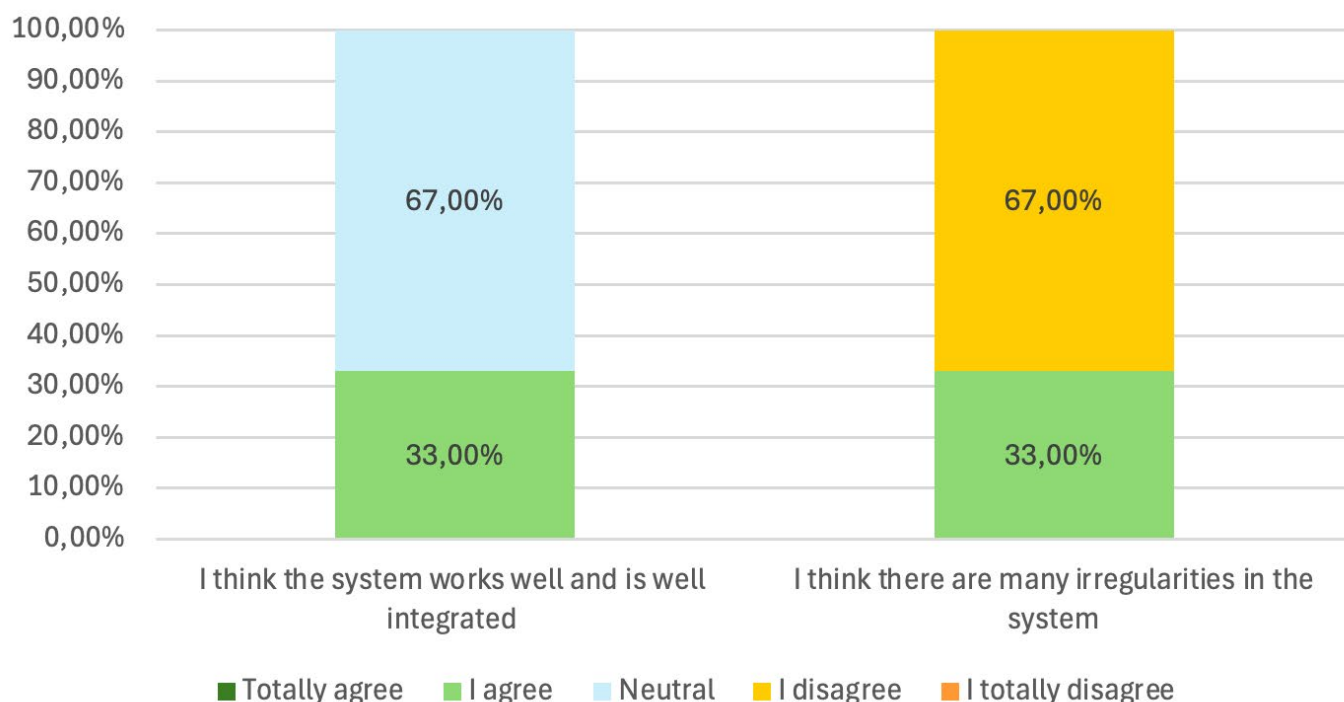


Figure 18. SUS Scale Results on Questions Related to the Care Process

Regarding the **safety of using drone technology** in the healthcare field for sample transport, all professionals

consider it to be a safe technology: 33% strongly agree and 67% agree.

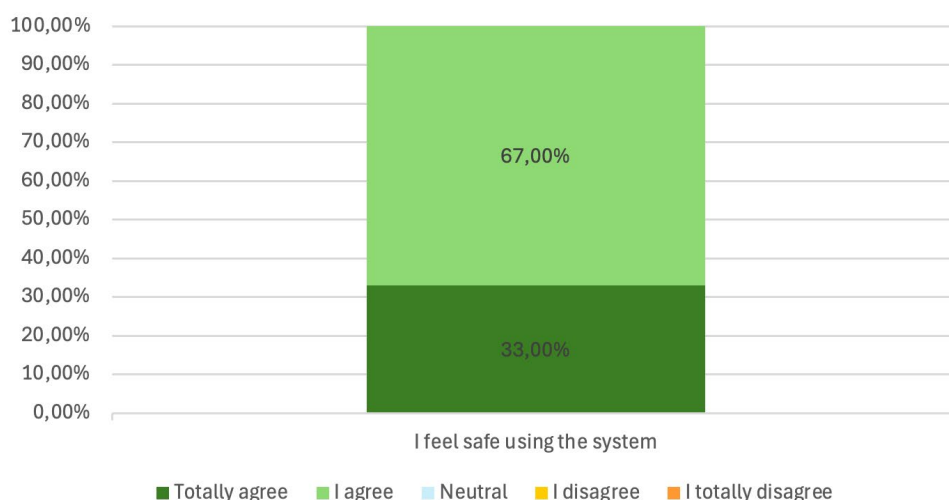


Figure 19. SUS Scale Results on Questions Related to the Care Process

These results show that **professionals strongly agree** that the system is simple and easy to use,

and that they feel confident using it; however, **technical competencies** are required to operate the technology.

6.3. Sample quality

All drone and van trips maintained sample temperatures within adequate range (5-20°C). As far as shaking, all samples received less than three collisions, which demonstrates enough stability when using both drones and vans.

and percentages for **difference in results between drone and road transportation.**

Average and standard diversions for each tested laboratory variable for all transported blood samples are shown below, as well as the difference

Table 5. Average and standard diversion for each laboratory variable for all transported blood samples using drones and vans, difference and percentage difference.

	Haemolysis Index	Potassium	LDH	Glucose
Drone	6,7 ± 4,1	4,5 ± 0,4 mmol/L	159,0 ± 27,9 U/L	95,4 ± 12,7 mg/dL
Van	14,6 ± 5,9	4,7 ± 0,4 mmol/L	171,4 ± 32,9 U/L	95,9 ± 13,0 mg/dL
Difference	7,9 ± 1,8	0,2 ± 0,0	12,4 ± 5,0	0,5 ± 0,3
Difference (change % compared to van)	47,7%	3,4%	6,6%	0,5%
Difference (normalised reference range %)	15,8%	11,0%	12,4%	1,7%

Haemolysis index (HI) was maintained within reference range (below 50) for both modes of transport. Thus, results for the remaining variables **are valid for both drones and vans**. Nevertheless, HI was noticeably lower by drone, 47.7% in comparison to the van, which contributes to better sample quality. The variation in potassium and LDH concentrations was lower, albeit considerable.

Glucose is the variable which has remained more stable, with only a 0.5% change. For all cases, concentrations were less with drones than with vans,

which can be related to the decrease in haemolysis. Normalised differences with reference ranges clearly show, such as in HI (15.8%), potassium (11%), and LDH (12.4%), differences are significant caused by the value range on which the variable moves.

In contrast, the normalised difference for glucose is much smaller (1.7%), which indicates great stability for this variable when using both modes of transportation.

T-tests show equivalent results: the difference between averages is

statistically meaningful for HI (p-value = $2.2 \cdot 10^{-8} < 0.05$), potassium (p-value = $8.4 \cdot 10^{-6} < 0.05$), and LDH (p-value = $3.6 \cdot 10^{-4} < 0.05$), while the difference is not significant for glucose (p-value = $0.16 > 0.05$).

More detailed results for each variable are presented below.

6.3.1. Haemolysis index

Figure 20 shows the **Bland–Altman plot of the hemolysis index**, where a high dispersion of values can be observed. Four values fall outside the

confidence interval, reinforcing the idea that the differences in hemolysis between the two methods are significant. Nevertheless, all HI values

remained within the reference range.

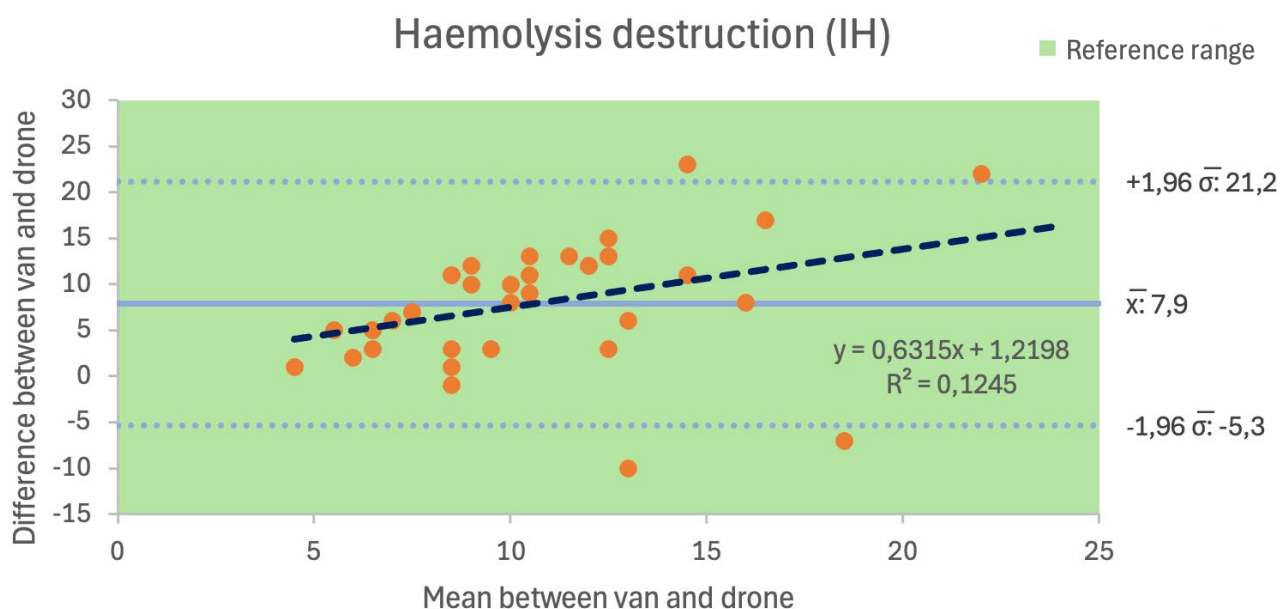


Figure 20. Bland-Altman haemolysis index, drone results compared to van ones

The trendline, with $R^2 = 0.12$, indicates a slight linearity level for these data and a tendency to increase the difference between both values as long as the average for HI increases.

Namely, when the higher HIs were obtained with the van transport, that same patient's HI sample was mostly lower with the drone.

There are only **three cases** in which HI is lower when using the van than the drone.

6.3.2. Potassium concentration

Figure 21 shows Bland-Altman potassium concentration. Relative value scattering can be observed, with only one value over and one under the trust range.

As regards to values outside of the reference range, the average will only be shown outside of the range for four cases in which the difference between

both transport methods is smaller and is clearly within the trust interval. Therefore, results indicating an alteration in the patient **are equivalent in both transport methods.**

Furthermore, the trendline is horizontal, with R^2 at almost zero, indicating the differences between both transport methods remain constant for all values.

Therefore, even though the t-test shows statistically significant differences between both transport methods for this variable, **the graph shows a sufficiently robust equivalence.**

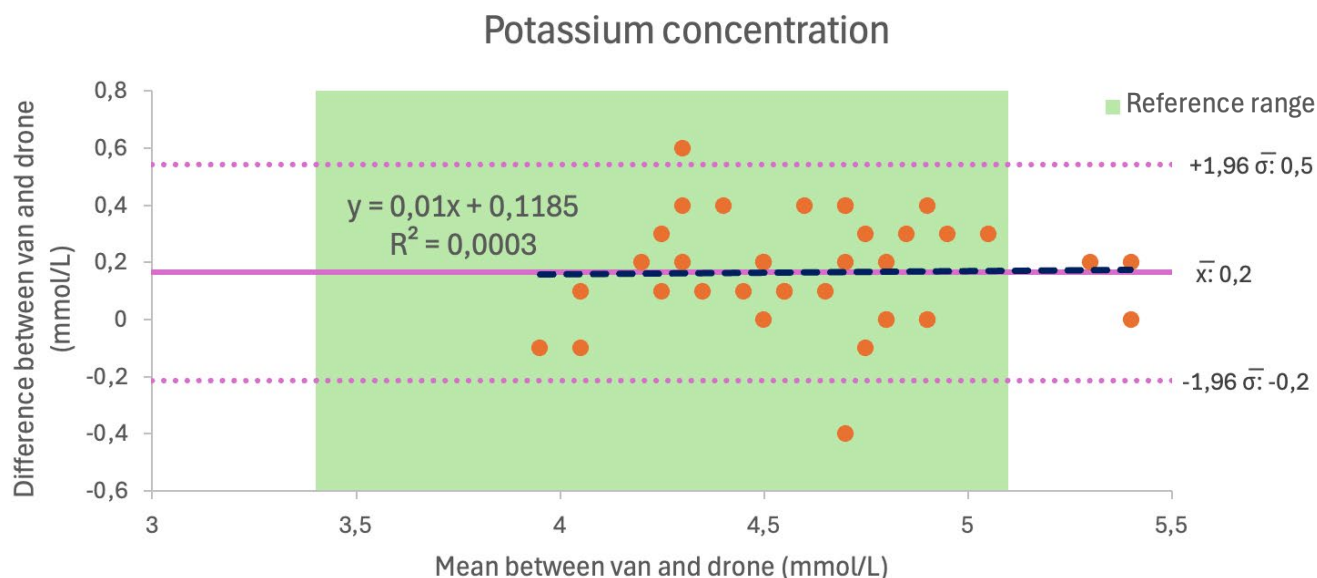


Figure 21. Bland-Altman potassium concentration, drone results compared to van ones

As far as **specific values** go, results were slightly lower with drone transport for the majority of patients. The same

value was obtained for four patients, and for another four the results were slightly higher by road transport

(negative differences in the graph).

6.3.3. Lactate Dehydrogenase (LDH) concentration

Figure 22 shows Bland-Altman LDH. A slight scattering of the points is observed, **all of which are quite close to the average difference**

and always within trust limits.

All values outside of the reference range are clustered within the trust

limit, which provides consistency for the diagnosis.

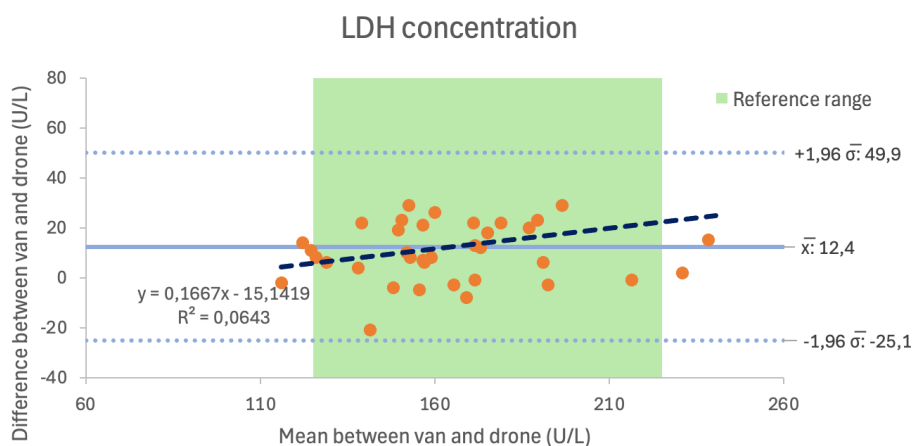


Figure 22. Bland-Altman LDH concentration, drone results compared to van ones

The trendline, with $R^2 = 0.06$, indicates a slight tendency to widen the difference between both values as the average LDH value rises, although this can be considered non-significant. For this variable, **results have mostly been lower for drones**, but there have also been quite a few lower values for

road transport. Therefore, although the t-test showed statistically significant differences between both transport methods for this variable, the graph shows a sufficiently robust equivalence.

It should be noted that one data value has been discarded as abnormal, as

it lies within five standard deviations from the average (average = 208.5; difference = 103).

6.3.4. Glucose concentration

Figure 23 shows the Bland-Altman plot of the glucose results. A moderate dispersion of the values can be

observed, with only one value above and one below the confidence interval. **The trend line is practically horizontal.**

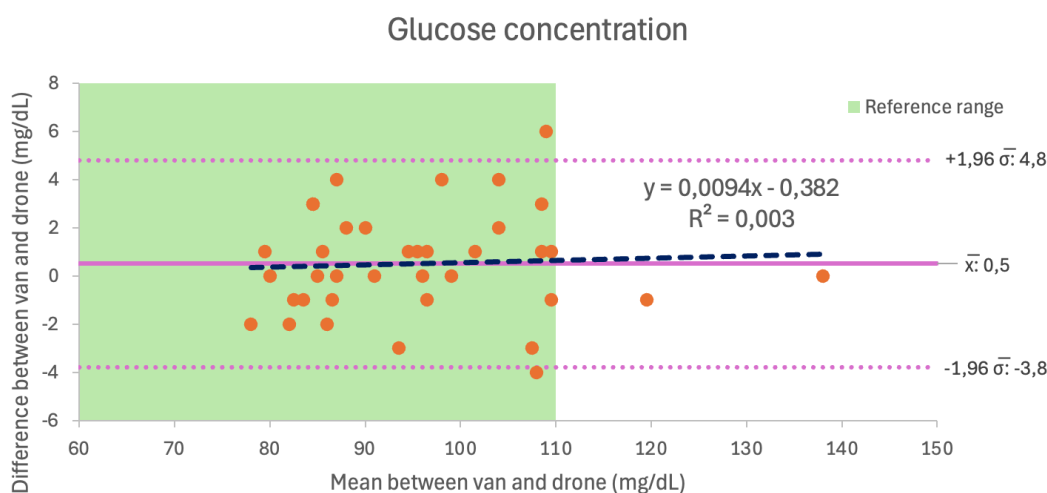


Figure 23. Bland-Altman plot of LDH concentration: drone results compared to the van

In this case, there are quite a few values also outside of the reference range, including the two values outside of the trust range. This can, in some cases, cause the result obtained from the drone and the van to vary so that it falls within the range for one transport method and outside for the other one, even though the graph

indicates that such cases are isolated and always within close values.

Smaller results have been obtained by drone transport for the most part, but there were also quite a few lower values by road; therefore, this difference can go either way.

Therefore, supported by the t-test results showing non-significant differences between both transportation methods, **it can be stated that there is good agreement between them for this variable.**

6.3.5. Correlation between indicators

Pearson correlations between different variables (potassium-HI, LDH-HI, and glucose-HI) appear to indicate that neither the differences in potassium nor in glucose compared to the differences in HI are not significantly correlated ($p\text{-value} = 0.366 > 0.05$, and $p\text{-value} =$

$0.788 > 0.0$, respectively). In contrast, a statistically significant moderate correlation was observed for LDH ($p\text{-value} = 2.7 \cdot 10^{-3} < 0.05$). The graphs on the following page show this correlation.

In the case of potassium, as shown in Figure 24, there appears to be a slight upward trend; however, its R^2 is 0.02 and, **therefore, a larger sample is required to draw conclusive results.**

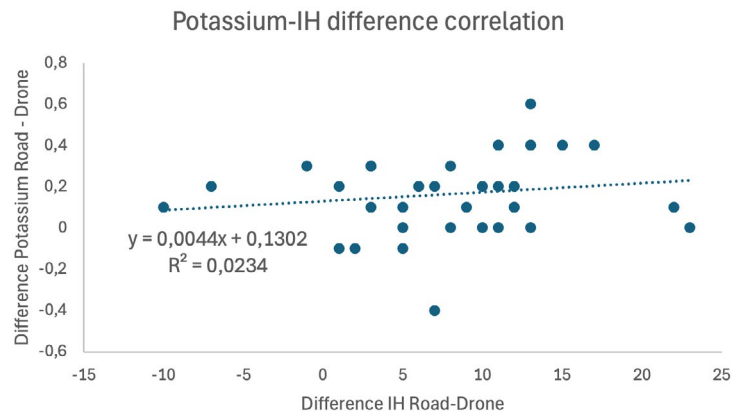


Figure 24. Differences correlation on potassium concentration compared to haemolysis index

In the case of LDH, a certain degree of correlation ($R^2 = 0.4$) can be observed between both indicators.

This appears to indicate that the increased difference in the haemolysis index translates into an **increase in**

the difference in LDH.

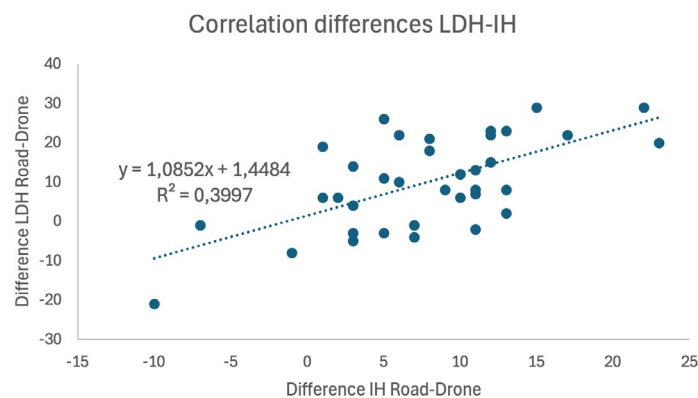


Figure 25. Differences correlation on LDH concentration compared to haemolysis index

As for the correlation for glucose levels, in Figure 26 **no apparent trend** is

discernible, although a larger sample is required to draw any conclusions.

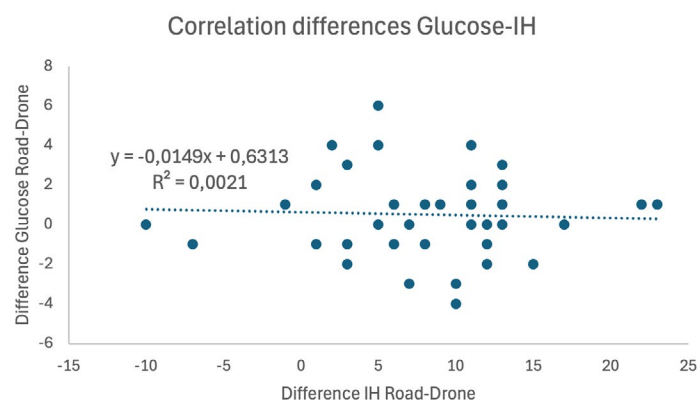


Figure 26. Differences correlation on glucose concentration compared to haemolysis index

6.4. Economic and environmental impact

The evaluation of the economic and environmental impact of drones in the healthcare sector enables an understanding of the implications of

this technology in terms of **costs and sustainability**. This analysis is essential for **assessing long-term viability** for projects using drones,

taking into account both the benefits and the potential costs associated to implementation and ongoing operations.

6.4.1. Costs

The cost of this project during piloting days includes, on the one hand, the **drone transport service cost** and, on the other one, **the cost of the nursing staff at the Primary**

Healthcare Centre who delivered the samples and **the hospital staff who collected them and took them to the laboratory**.

The cost of the drone transport service for this project amounted to approximately €34,184, a figure obtained by adding three categories up:

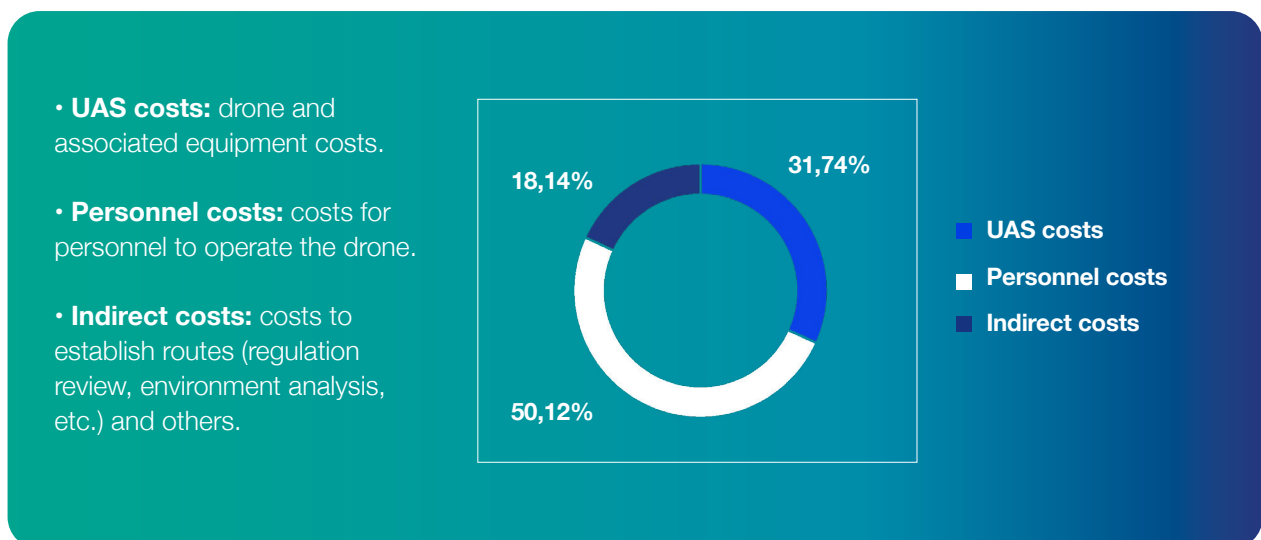


Figure 27. Distribution of costs for the drone transport service project.

As far as **staffing costs** at the Primary Healthcare Centre and hospital, including time spent transporting samples and the collection time, staff have spent on average about three minutes per day.

Since setbacks may occur during this phase of the care flow that could delay proceedings, a reference value of 15 minutes for healthcare staff time has been used to calculate staffing costs. Thus, a cost of €10 per healthcare professional per piloting day, €50 over

the two weeks, has been obtained.

Therefore, total piloting cost was €34,234.

6.4.2. Environmental impact

Based on the approximations and calculations carried out, it was determined that each trip in a standard van from the Primary Healthcare Centre to the Hospital (10.5 km) emits 2,640 g of CO².

The drone has two 22.2 V batteries with a 22 Ah capacity, so the electrical energy it consumes is 0.98 kWh. The average time for drone trips was 7 min 32 s. With these parameters, the resulting value obtained is 31.93 g CO²

equivalent per trip.

Hence CO² emissions from the drone dropped by 98.79% in comparison to those by a van.

2.640 g CO₂ eq

Van emissions
per trip

31,93 g CO₂ eq

Drone emissions
per trip

98,79%

CO² percentage
decrease

7. Discussion

This project has demonstrated the **potential of drone technology as a means of transporting biological samples that can flexibly** and effectively complement healthcare logistics in rural areas, such as La Garrotxa. Drone transport time accounted for approximately a **quarter of the time** of van transport, with a more consistent duration and less exposure to road-related variables, such as traffic volume or road and track conditions. Furthermore, the drone demonstrated **good operational capabilities in light rain**, although it was limited in heavy rain and strong winds. Drones can experience difficulties under these conditions, as a result an alternative mode of transport is needed.

During the test performance, good **usability results** were observed, although the difference from the good usability threshold is marginal. During this project, the reception of samples at the hospital was carried out by healthcare staff, but in the future this task could be performed by an administrative assistant or could even be avoided by automating the process. Additionally, it would be highly advisable to introduce devices and platforms that enable the management of transport notifications and alerts, thereby facilitating better coordination. Furthermore, it is necessary to set up **landing platforms** that improve loading onto and unloading from the drone.

The sample quality results are satisfactory and interesting, since haemolysis values obtained using the drone are on average 47% lower than those obtained when using the van. These results may be influenced by the fact that road transport's departure time has always been after the drone's take-off time, as well as by the movements of the van on the road.

As for the laboratory variables, potassium values obtained by drone are slightly lower. There is also a slight downward bias concerning LDH values.

In this regard, a certain correlation is observed between the increase in LDH value differences and those in the haemolysis index: a decrease in haemolysis could be related to a decrease in LDH values. And last, the **glucose concentration** has proved sufficiently stable, with no significant differences between both methods of transport.

In terms of costs, it has been found that in a scenario of a single trip per day between the two centres, the cost of drone transport is higher than that of van transport. The cost of the personnel operating the drone is the most significant component. Increasing the frequency of drone flights (which could be achieved in the short-term) would allow these costs per flight to be optimised, as well as improve the efficiency of the healthcare system.

Since current road transport is limited to a morning service with fixed timetables, **drones could enable more frequent, unscheduled departures** tailored to immediate needs, preventing patients from having to travel to the hospital for urgent diagnoses. This flexibility and adaptability would provide patients with benefits in terms of time and convenience, especially those who live further away from the healthcare centre or have difficulty moving about and would reduce the cost of patient transport in cases where they cannot travel unaided.

In the **mid- to long-terms**, considering factors such as drone depreciation, battery energy costs, and drone insurance, the factors that would have the greatest impact on improving efficiency are transport with deliveries to multiple healthcare centres (mid-term), and increasing the number of drones that a single pilot can operate (long-term).

In a future scenario (3-5 years), the combination of the three aforementioned factors (short-, mid-, and long-terms) could allow the cost per trip to be reduced compared to road transport costs.

Nevertheless, further projects are needed to expand the number of samples and implement process improvements such as those mentioned before in order to increase and consolidate the evidence for the use of drones as a method of transporting biological samples.

8. Conclusions

This project has enabled the scheduled transport of blood samples from Primary Healthcare Centre Vall d'en Bas to the analysis laboratory at Olot Hospital to be carried out successfully.

Transport was carried out on the five scheduled days, and, in total, 108 biological samples were transported by drone, 37 of which were blood samples. Thus, **efficiency and effectiveness** of this mode of transport were evaluated in a real-life setting.

The use of drones has proven to be a **viable logistic solution**, delivering a **significant reduction in transport time** (74.3% less) compared with road transport, and a more consistent trip time.

The **quality of the samples transported has also been favourable, both in terms of temperature**, shaking, and laboratory variables. More specifically, the haemolysis index has been reduced by 47.7%. Furthermore, thanks to the use of an electric drone, CO₂ emissions **have been reduced** by 98.8% when compared to van transport.

As far as drone usability is concerned, an initial analysis indicates a **good capacity for integrating** the device into the care flow, although there is room for improvement (SUS score 74/100). In the future, the implementation of technological and operational improvements will enable structuring, improvement, and optimisation of service costs.

Therefore, **drones will open the door to new transport services that could represent a breakthrough in biomedical material logistics distribution**. Its implementation can also improve the efficiency and quality of healthcare services, as well as contributing to less polluting gases.

Finally, a broader use of drones on unscheduled routes **would enable primary healthcare centres to expand services**, reduce patient waiting times, and avoid unnecessary trips, offering a faster and more convenient solution that directly impacts the quality of healthcare and patient satisfaction.

9. References

-
- 1.** Infografia Aplicació de drons en l'àmbit de la salut - TIC Salut Social [Internet]. [quoted 31st October 2024]. Available at: https://ticsalutsocial.cat/wp-content/uploads/2023/10/Cartell_Drons_TICSalut_Bo.pdf
 - 2.** Informe-Integracio-de-Drons-a-Entorn-Salut.pdf [Internet]. [quoted 10th September 2024]. Available at: <https://ticsalutsocial.cat/wp-content/uploads/2024/05/Informe-Integracio-de-Drons-a-Entorn-Salut.pdf>
 - 3.** España termina 2023 con más de 94.000 operadores de drones registrados en AESA | AESA-Agencia Estatal de Seguridad Aérea - Ministerio de Fomento [Internet]. [quoted 7th October 2024]. Available at: <https://www.seguridadaerea.gob.es/es/noticias/espana-termina-2023-con-mas-de-94000-operadores-de-drones-registrados-en-aesa>
 - 4.** Concepto U-space | Ministerio de Transportes y Movilidad Sostenible [Internet]. [quoted 31st October 2024]. Available at: <https://www.transportes.gob.es/aviacion-civil/politica-espacio-aereo/portal-para-la-coordinacion-del-u-space-en-espana/concepto-ospace>
 - 5.** DCA. Olot prova amb èxit el transport de mostres biològiques amb drons [Internet]. DCA. 2023 [quoted 14th December 2023]. Available at: <https://dca.cat/ca/2023/05/olot-prova-amb-exit-el-transport-de-mostres-biologiques-amb-drons/>
 - 6.** Mapa Vall d'en Bas.pdf [Internet]. [quoted 9 October 2024]. Available at: <https://www.ddgi.cat/municipis/ValldenBas/mapes/Mapa%20Vall%20d'en%20Bas.pdf>
 - 7.** Sant Esteve d'en Bas.pdf [Internet]. [quoted 9 October 2024]. Available: <https://www.ddgi.cat/municipis/ValldenBas/mapes/Sant%20Esteve%20d'en%20Bas.pdf>
 - 8.** adr_2023_volumen_i_.pdf [Internet]. [quoted 9 October 2024]. Available at: https://cdn.mitma.gob.es/portal-web-drupal/mitma/docs/adr_2023_volumen_i_.pdf
 - 9.** dgr-65-es-pi650.pdf [Internet]. [quoted 9 October 2024]. Available at: <https://www.iata.org/contentassets/b08040a138dc4442a4f066e6fb99fe2a/dgr-65-es-pi650.pdf>
 - 10.** UAS/Drone Operations – Specific Category | AESA – Spanish Aviation Safety and Security Agency – Ministry of Development [Internet]. [cited 24 January 2024]. Available at: <https://www.seguridadaerea.gob.es/es/ambitos/drones/operaciones-uas-drones/operaciones-con-uas-drones---categoria-especifica>
 - 11.** ENAIRE Drones [Internet]. [cited 14 December 2023]. Available at: <https://drones.enaire.es/>
 - 12.** GEI CeroCO Calculation [Internet]. [cited 25 October 2024]. Available at: <https://www.ceroco2.org/calculadoras/home>
 - 13.** Electricity Emission Factor: the Electricity Mix. Climate Change [Internet]. [cited 10 October 2024]. Available at: https://canviclimatic.gencat.cat/es/actua/factors_demissio_associats_a_lenergia/
-

APPENDIX I – SUS scale

The SUS scale is a usability scale which consists of 10 items on a Likert scale.

This scale assigns a value from 1 to 5 to answers from Completely disagree (1) to Completely agree (5):

	COMPLETELY DISAGREE	DISAGREE	NEUTRAL	AGREE	COMPLETELY AGREE
1. I would like to use this system more often					
2. I believe this system is harder than needs be					
3. I believe the system is straightforward and easy to use					
4. I need technical help when using the system					
5. I believe the system works correctly and is properly integrated					
6. I believe there are many system irregularities					
7. I believe most people can learn this system quickly					
8. I believe this system requires a lot of time					
9. I feel safe using this system					
10. I believe many things must be learnt before using this system					